Color of Uncooked and Cooked Broiler Leg Quarters Associated with Chilling Temperature and Holding Time[1]

B. G. Lyon*[2] and C. E. Lyon†

*Quality Assessment Research Unit, and †Poultry Processing and Meat Quality Research Unit, USDA-Agricultural Research Service, Russell Research Center, P.O. Box 5677, Athens, Georgia 30604-5677

ABSTRACT Discoloration of raw or cooked tissue can occur from cell disruptions and blood migration caused by slow or variable chilling rates. Color parameters established by the Commission International D'Eclairage for measuring lightness, redness, and yellowness (L*, a*, and b*, respectively) were determined on two groups (A and B) of uncooked and cooked leg quarters chilled at +4, 0, –3, –12, or –18 C. At Day 7, group A was evaluated for color, and group B was moved to –18 C for seven additional days and then evaluated. Group B represented cooling, freezing, thawing, and cooking steps. Color was measured on surfaces of thawed, uncooked parts (UCS), on surfaces of cooked parts (CS) 75 or 85 C internal temperature), and on cooked meat (CM) adjacent to the femur. UCS samples at –3 C were significantly redder (a* = 8.91) than –18 C samples (a* = 5.04). The A-CS a* values showed a significant interaction between chill temperature storage and internal temperature (IT). Samples at 75 C IT had higher a* values (redder). CM samples held at +4 and 0 C were significantly lighter (higher L* values). A significant interaction effect occurred for CM a* values due to storage chill temperature and IT. Generally, 75 C IT samples were redder (higher a* values). UCS and CS color was not influenced by chilling at +4 to –18 C for 7 d and then at –18 C for 7 d. CM was affected by a combination of chill temperature history and IT.

(*Key words*: poultry, leg quarters, fresh, frozen, color)

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INTRODUCTION

Regulations require that poultry carcasses be chilled to 7 C (45 F) within 2 h of processing (USDA, 1972). This is usually accomplished by water chilling from 45 min to more than 1 h. Subsequent to distributing the product to supermarkets for retail sale as "fresh" or as "frozen" poultry, the processor must hold the product at temperatures that assure microbial safety, provide optimum consumer quality, and meet labeling requirements. Temperatures at which samples are chilled and held might range from +4 (refrigerator temperature) to –18 C (frozen), depending on use and distribution plans. However, steps that are taken by the retailer and by the consumer in product storage, handling, and cooking will also affect final product quality.

Lyon et al. (2001) reported that microbial and sensory changes in broiler breast fillets were little affected by chilling temperatures and freezing. The study was conducted on deboned broiler breast fillets under controlled conditions in order to study possible effects on quality that might occur from temperature fluctuations during the continuum from processing through distribution to supermarket. In reality, other product forms, such as whole carcasses or cut-up parts that include the bone, must oftentimes be chilled and stored. These forms would also be susceptible to quality changes due to temperature fluctuations. Leg quarters, in particular, may be affected due to the dark meat and percentage of bone that accompanies the muscle.

Color problems of frozen parts containing bone and dark muscle (thigh and drum) have been the subject of several reports (Brant and Stewart, 1950). An early report by Koonz and Ramsbottom (1947) indicated that hemoglobin content of bones was greater in young animals. When defrosting immature chickens, some pigment escaped through porous, spongy, incompletely calcified walls of the bones and accumulated on tissues. When cooked, this tissue appeared darker. Spencer et al. (1961) also found darkening in broilers subjected to freezing but not in nonfrozen controls. Lyon et al. (1976) demonstrated that meat and bone darkening of thigh pieces was related to pigment migration from the femur to tissue. Measure-

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[2]To whom correspondence should be addressed: bglyon@saa.ars.usda.gov.

Abbreviation Key: a* = redness; b* = yellowness; CM = cooked middle; CS = cooked surfaces; IT = internal temperature; L* = lightness; UCS = uncooked surfaces.

ments were made with a colorimeter to assess the degree of change due to rate of freezing (air blast and coolant immersion). Lyon and Lyon (1986) examined carcass bleed-out times and multiple preparation steps in the final battered and breaded fried products from breast meat. Variations in bone discoloration of the final products were found to relate more to preparation method (precook, freeze, reheat) than to bleed-out time.

The first objective of this study was to evaluate leg-quarter color changes that could be related to storage at various chill temperatures for a period of 7 d. The second objective was to determine color of leg quarters that had also been held at various chill temperatures, followed by storage at –18 C with subsequent thawing and cooking.

MATERIALS AND METHODS

Samples and Treatments

Forty carcasses were obtained post-chill from a local processor and transported to the laboratory where the hind portions were removed, trimmed of excess abdominal fat and skin, and then halved with a circular saw. The left and right leg thigh quarters from each carcass were individually packaged in double-lined, 35 × 50 cm plastic bags[3] that were tied and coded to identify quarters from the same bird. The bagged samples (matched quarters) from eight birds were randomly selected and assigned to one of five individual temperature-controlled walk-in chambers set at +4, 0, –3, –12, or –18 C and then placed in single layers on stainless steel racks in each chamber. Each chamber[4] was approximately 2.3 m wide × 2.1 m high × 2.6 m deep. Temperatures of the chambers were recorded, monitored, and controlled 24 h per day to within 2 C during the study, using thermocouples inserted through a channel in the wall.

At Day 7, the quarters from four birds at each temperature were removed for color evaluation after thawing overnight at 4 C and after cooking in ovens set at 177 C (350 F). Two sets (four quarters) were cooked to internal temperatures (IT) of 75 C and two sets (four quarters) were cooked to 85 C IT. IT were measured with a hand-held thermometer equipped with probe.[5] The remaining four sets of quarters at chill temperatures +4, 0, –3 and –12 C were all moved to a –18 C chamber for seven additional days of storage. At Day 14, these samples were removed for color evaluation after thawing and after cooking to 75 or 85 C IT, as described above.

Color Evaluation

The CIELAB color space model (CIE, 1978) was used and color values (L*, a*, b*) were recorded using a reflectance colorimeter.[6] The colorimeter was calibrated for illuminant C, representing average daylight with a color temperature of 3746 C (6774 F) using the standard white reflective plate supplied by the manufacturer (Plate No. 12331139). L* values represented lightness (0 = dark to 100 = light); a* and b* values measured chromaticity coordinates, where positive a* values indicate redness and positive b* values indicate yellowness.

Color was measured at three locations under the skin on surfaces of thawed, uncooked thighs (UCS); two points were on the top surface under the skin and either side of the femur line, and the third was on the under side. The same three locations were sampled on surfaces of the thighs cooked to 75 or 85 C internal temperature (CS). Additionally, color was measured at three locations on cooked meat (CM) adjacent to the femur, after knife-cutting along the bone to expose the meat tissue. The colorimeter contact arm was placed directly in contact with the tissue. The sampling window on the colorimeter was 8 mm in diameter, so care was taken to place the instrument at the same positions when tissue was sampled for the different pieces. Each recorded L*, a*, and b* value was the average of three instrumental readings.

Statistical Analysis

The L*, a*, and b* data were analyzed using the General Linear Models (GLM) procedure of SAS[7] (SAS Institute, 1998). An experimental design of 5 × 2 was used for main effects of chill temperature and storage group, with four birds (eight quarters) in each cell. Bird right and left quarters, considered as replicates for uncooked samples, were not significant and subsequently pooled into the error term. IT was also a main effect in the cooked samples. Residual error term was used to test main effects. Differences were considered significant when $P < 0.05$. Means were separated using Duncan's multiple range test. Mean variations were calculated as standard error of the mean. Independent sample t-tests were conducted comparing storage groups A versus B within chill temperature.

RESULTS AND DISCUSSION

The temperatures chosen for the study ranged from normal refrigerator temperature (+4 C) to freezer temperatures (–18 C). These temperatures encompass the range above and below the final regulations issued by FSIS (USDA, 1996) that allowed the label "fresh" for poultry products that had never been below –3 C, with a tolerance limit of 0.56 C below –3 C within an inspected plant, or a tolerance limit of 1.11 C below –3 C once outside the plant, that is, in commercial transport. These temperatures include the range of 0 to –3 C, at which water freezes. This study also included treatments to simulate common consumer practices of storing, freezing, thawing, and then cooking chicken.

The L*, a*, and b* values of raw thawed, uncooked samples from Groups A and B are graphed in Figures 1 and 2 to show the L*, a* and b* values and their relation-

[3]Cryovac Sealed Air Corp., Duncan, SC.
[4]Nolin Mfg., Montgomery, AL.
[5]Doric Digital Thermometer, Model 450-ET, Doric Scientific, San Diego, CA.
[6]Minolta Chroma Meter CR-200, Minolta, Ramsey, NJ.
[7]SAS Software Version 7, SAS Institute, Cary, NC.

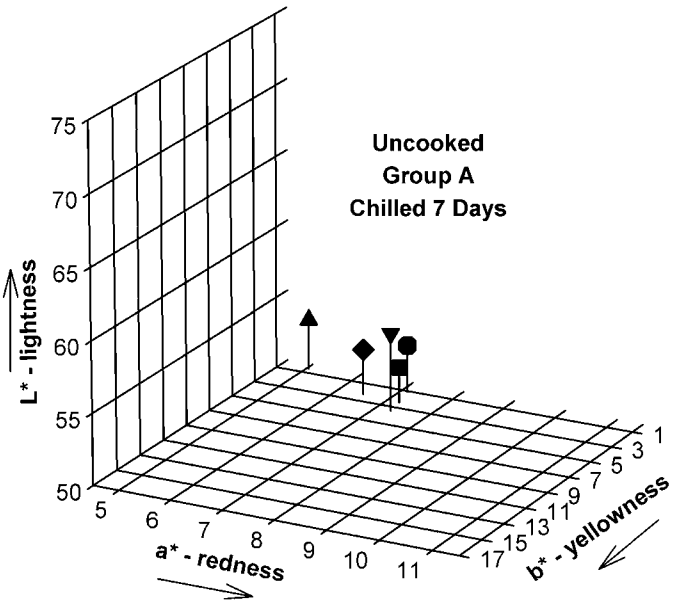

FIGURE 1. CIE L* a* b* values (means) plotted for uncooked leg quarter surfaces (UCS) stored 7 d at +4, 0, –3, –12 and –18 C (Group A). Based on CIE color system, L* values represent lightness on a scale of 0 = black to 100 = white; positive a* values represent redness; positive b* values indicate yellowness. Temperature symbols: ▲ = –18 C, ◆ = –12 C, ■ = –3 C, ▼ = 0 C, ● = +4 C.

ships to each other. The L* values are plotted on the vertical axis, and the a* and b* values are plotted on x and y axes. Each sample's color values for L*, a*, or b* can be estimated from the appropriate axis, and the sample's overall point in the color space can be discerned by considering the intersection of all three values.

L* values (lightness) of chill-temperature samples within Group A were not different and ranged from 52.46 ± 1.37 to 55.39 ± 0.88 (Figure 1). Likewise, Group B L* values were not different among the chill temperatures (excluding the –18 C samples), with values ranging from 50.97 ± 0.84 to 53.22 ± 1.09. However, overall L* values for samples from Group B were lower (darker) than values for samples from Group A. Comparisons between the storage regimes within each chill temperature indicated that the differences between Group A and B could be attributed to the 0 C chill temperature, with samples from Group A significantly lighter (55.39 ± 0.88; Figure 1) than samples from Group B (53.22 ± 1.09; Figure 2). Lyon et al. (1976) also found lower L* values (darker) for frozen versus nonfrozen samples.

The a* values (redness) of Group A UCS held at –18 C were lower (5.04 ± 0.68, less red) than samples stored at –3, 0, or +4 C (7.13 to 7.28) but similar to –12 C samples (6.48 ± 0.61). Differences in redness attributed to chill temperature (Group A) were negated by subsequent storage at –18 C for seven additional days (Group B). Values pooled over chill temperature indicated no differences between samples in Groups A and B (6.64 ± 0.30 vs. 6.58 ± 0.32). The b* values (yellowness) for samples held at 0 C were higher (more yellow) than the –18 C samples in Group A. There were no differences in sample b* values between chill temperatures in Group B. When groups A and B were combined to test overall chill temperature effects, samples from +4 and 0 C were different from –18 C. However, the mean b* value for samples held at –18 C was extremely low (0.51). Pooled t-tests comparing groups A and B within temperature indicated a difference in b* values between A (1.09 ± 0.82) and B (3.86 ± 0.79) for the +4 C temperature (refrigerator storage temperature). When UCS samples were placed in –18 C temperatures for seven additional days (Group B), there were no differences in L*, a*, or b* values among samples across the various chill temperatures. Hard freezing after storage from +4 to –12 C tended to negate any differences noted in comparing temperatures within a group.

L* and b* values of CS from Group A that were cooked to 75 or 85 C indicated no differences due to chill temperature when analyzed within cooked temperature (data not shown). In general, b* values were all higher for 85 C pieces compared to their 75 C counterparts and differed when pooled over chill temperatures (15.15 ± 0.27 vs. 13.40 ± 0.22, respectively, for 85 C vs. 75 C). When pooled over IT, b* values were not different due to chill temperature (Figure 3). Within each IT group, chill temperatures showed no differences, and pooled over IT, there were no group differences. However, when pooled over group, chill temperature a* values showed a difference between +4 C samples (higher, more red) than other chill temperatures. The a* values (redness) were higher for the +4 C samples than for the 0, –3, and –12 C samples but were not different from the –18 C pieces (Figure 3).

Figure 4 represents color values of samples from Group B, placed in –18 C after initial chill storage treatments.

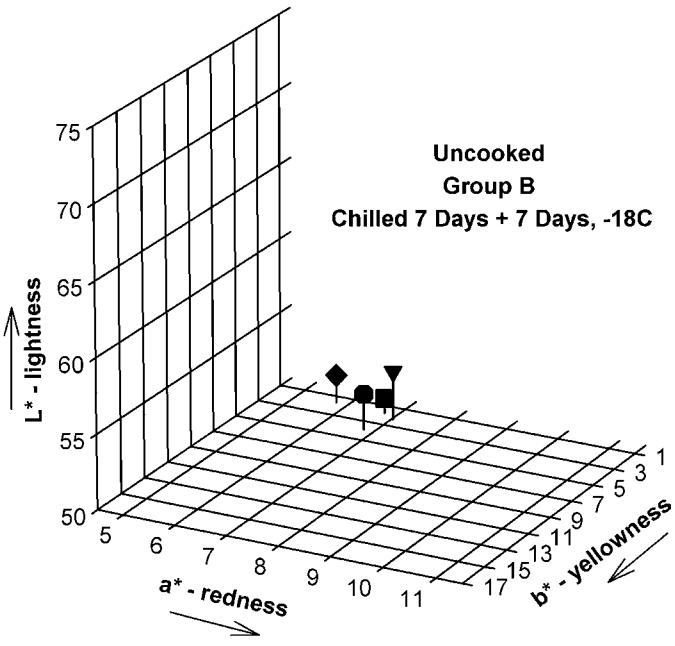

FIGURE 2. CIE L* a* b* values (means) plotted for uncooked leg quarter surfaces (UCS) stored 7 d at +4, 0, –3, and –12 C and then moved to –18 C for 7 additional d (Group B). Based on CIE color system, L* values represent lightness on a scale of 0 = black to 100 = white; positive a* values represent redness; positive b* values indicate yellowness. Temperature symbols: ◆ = –12 C, ■ = –3 C, ▼ = 0 C, ● = +4 C.

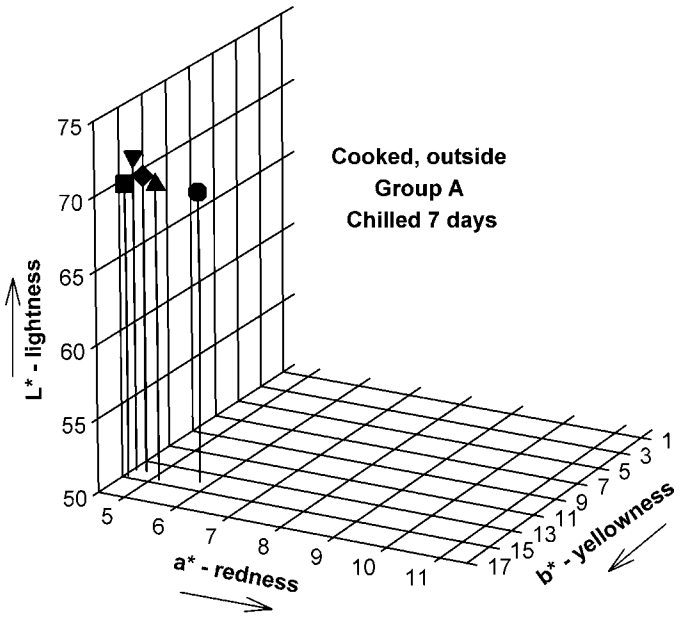

FIGURE 3. CIE L* a* b* values (means) plotted for surfaces of cooked leg quarters (CS) stored 7 d at +4, 0, –3, –12 and –18 C (Group A). Based on CIE color system, L* values represent lightness on a scale of 0 = black to 100 = white; positive a* values represent redness; positive b* values indicate yellowness. Temperature symbols: ▲ = –18 C, ◆ = –12 C, ■ = –3 C, ▼ = 0 C, ● = +4 C.

There were no differences in either L* or a* values. The b* values were significantly higher for –12 C than for –3 C samples. Higher b* values were attributed to the samples that were cooked to 85 C IT.

Color of the interior cooked meat tissue (CM) near the femur (Table 1) indicated that L* values were significantly higher (lighter) for the +4 and 0 C samples compared to –3 and –12 C samples. The a* values (redness) were higher for the 75 C samples (9.99 ± 0.40) than for 85 C samples (8.47 ± 0.22). Samples chilled at –3 C or cooler for 7 d had higher a* values (redder) when cooked to 75 C. B* values for the –12 C samples were lower than for other samples.

Differences in L* values of CM in Group B (Table 1) were due to cook temperatures more than to initial test chill temperature. The samples that were cooked to 75 C were darker (lower L* values). Inside meat tissue of these samples also had higher a* values, especially those initially chilled at +4 and 0 C for 7 d prior to storing at –18 C. Cooking these samples to the higher temperature of 85 C gave a* values more similar to those obtained from samples stored at –3 to –18 C for 7 d. The b* values for the +4 C samples were higher than the –3 C samples.

Using –18 C as a reference for "frozen" treatments, +4 and 0 C samples at the two storage treatments (Group A, 7 d at chill temperatures; Group B, additional 7 d at –18 C) differed the most in color values. Samples at –3 C had the least color difference. At this temperature, phase transition of the free water may not be complete.

Visual appearance, especially color, of processed poultry chilled at temperatures ranging from +4 C to –18 C is of interest to consumers and processors. Discoloration of raw or cooked tissue can occur from cell disruptions and blood migration caused by slow chilling rates, which may include the temperatures 0 and –3 C. The L*, a*, and b* color values (measuring lightness, redness, and yellowness, respectively) determined on uncooked and cooked leg quarters chilled at temperatures ranging from

TABLE 1. Mean (± SEM) color (L*, lightness; a*, redness; and b*, yellowness) of cooked thigh meat adjacent to femur bone following chill-storage treatments

Chill temperature (C)	Group A			Group B		
	75 C	85 C	Mean	75 C	85 C	Mean
	L* values					
–18	61.29 ± 1.44	62.09 ± 2.11	61.69^{ab} ± 1.25	—	—	—
–12	57.49 ± 2.81	58.57 ± 2.24	58.02^{b} ± 1.75	61.87 ± 1.60	63.40 ± 2.57	62.36^{a} ± 1.48
–3	58.04 ± 1.98	62.95 ± 1.53	60.49^{b} ± 1.32	62.71 ± 1.84	60.45 ± 2.13	61.58^{a} ± 1.39
0	64.62 ± 1.51	65.82 ± 1.13	65.22^{a} ± 0.92	57.59 ± 2.53	63.89 ± 1.85	60.74^{a} ± 1.66
+4	66.07 ± 1.38	64.23 ± 1.12	64.84^{a} ± 0.87	60.39 ± 2.32	68.31 ± 1.40	64.35^{a} ± 1.56
Mean	60.99^{x} ± 0.98	62.73^{x} ± 0.79		60.63^{y} ± 1.05	64.01^{x} ± 1.06	
	a* values					
–18	10.50 ± 0.92	8.33 ± 0.52	9.41^{ab} ± 0.56	—	—	—
–12	10.40 ± 0.83	8.30 ± 0.71	9.34^{ab} ± 0.57	9.72 ± 0.57	8.72 ± 0.73	9.21^{b} ± 0.46
–3	11.74 ± 1.05	8.37 ± 0.45	10.05^{a} ± 0.65	9.46 ± 0.83	9.43 ± 0.57	9.44^{ab} ± 0.49
0	8.57 ± 0.30	7.76 ± 0.32	8.16^{b} ± 0.23	13.09 ± 1.59	9.42 ± 0.87	11.25^{a} ± 0.96
+4	7.54 ± 0.54	9.61 ± 0.34	8.91^{ab} ± 0.36	12.85 ± 0.98	6.54 ± 0.52	9.69^{ab} ± 0.85
Mean	9.99^{x} ± 0.40	8.47^{y} ± 0.22		11.27^{x} ± 0.56	8.52^{y} ± 0.37	
	b* values					
–18	14.27 ± 0.41	13.64 ± 0.42	13.95^{a} ± 0.29	—	—	—
–12	12.48 ± 0.43	12.68 ± 0.28	12.57^{b} ± 0.25	14.65 ± 0.60	14.31 ± 0.56	14.48^{ab} ± 0.39
–3	13.52 ± 0.49	13.61 ± 0.43	13.56^{a} ± 0.31	13.12 ± 0.59	13.57 ± 0.53	13.34^{b} ± 0.39
0	13.99 ± 0.43	14.64 ± 0.38	14.31^{a} ± 0.28	13.00 ± 0.68	15.38 ± 0.56	14.18^{ab} ± 0.49
+4	13.92 ± 0.69	13.42 ± 0.38	13.58^{a} ± 0.33	14.74 ± 0.51	14.72 ± 0.33	14.72^{a} ± 0.29
Mean	13.60^{x} ± 0.22	13.59^{x} ± 0.18		13.87^{x} ± 0.31	14.49^{x} ± 0.26	

^{a,b}Means (n = 8) within column with same superscript are not significantly different ($P > 0.05$).

^{x,y}Means (n = 20, group A; n = 16, group B) in a row by storage group with same superscript are not significantly different ($P > 0.05$).

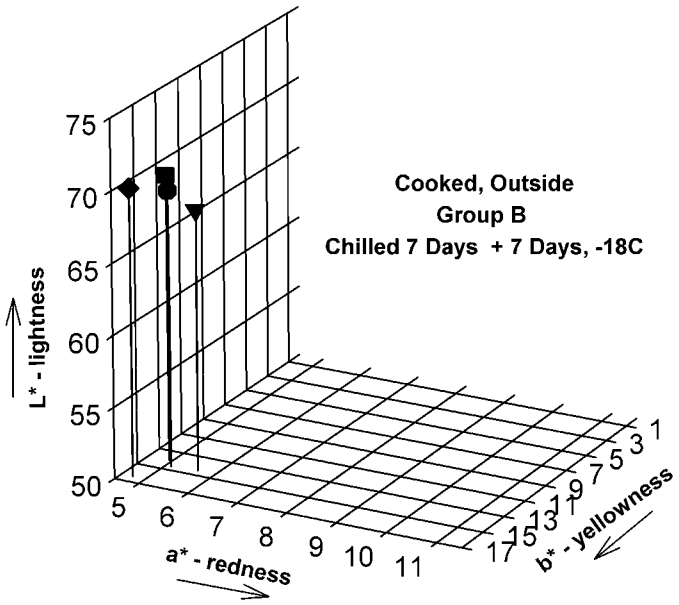

FIGURE 4. CIE L* a* b* values (means) plotted for outside surfaces for cooked leg quarters (CS) stored 7 d at +4, 0, –3, and –12 C and then moved to –18 C for 7 additional d (Group B). Based on CIE color system, L* values represent lightness on a scale of 0 = black to 100 = white; positive a* values represent redness; positive b* values indicate yellowness. Temperature symbols: ◆ = –12 C, ■ = –3 C, ▼ = 0 C, ● = +4 C.

+4, 0, –3, –12, or –18 C indicated that surface color of leg quarter tissue under the skin was not influenced by chilling at +4 to –18 C for 7 d and then at –18 C for 7 d. Color of cooked meat adjacent to the femur was affected by a combination of chill temperature history and IT. For samples cooked to 75 C IT, those that were chilled at 0 and +4 C, followed by storage at –18 C had meat color significantly redder than meat color in samples chilled at –3 and –12 C. Cooking to 85 C IT negated color differences attributed to the chill temperatures.

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